DEFENCE R&D DÉFENSE

Field Detection of Depleted Uranium Final Report of Tasking W28476KR00Z (DSSPM)

D.S. Haslip, T. Cousins, D. Estan and T.A. Jones
Defence Research Establishment Ottawa

Defence R&D Canada
DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL MEMORANDUM
DREO TM 2000-049
June 2000

National Defence Défense nationale

Canada

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Radiation Effects Group
Space Systems and Technology Section

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Project
DSP 00002199

ABSTRACT

At the request of Defence Services Procurement Project 00002199, DREO has undertaken a study to examine the capabilities of commercial radiation detection equipment for the detection of depleted uranium (DU) on the battlefield. This work is intended to guide doctrine development for procedures to be followed where DU use or contamination is suspected. This work involved some spectroscopic studies of DU munitions, and detection trials with a variety of DU sources, from large spheres to low-activity area sources. The effect of shielding by tissue was also studied, and a trip was made to the Superbox facility at Aberdeen Proving Ground to assess the possibility for field trials of Canadian Forces (CF) equipment in an actual DU-contaminated environment.

This study established a number of important facts regarding DU detection by the CF. It was shown that while commercial equipment can detect α, β, and γ emission by uranium sources, β detection is by far the preferred method to be used for contamination surveys. The sensitivity of the ABP-100 alpha-beta probe (in β mode) for DU is approximately 0.5 Bq/cm^2 when the contamination is over a large area. However, because the attenuation of beta radiation by tissue is so great, the efficacy of this detector for detecting shards of DU embedded in wounds is much poorer. Thus, while these devices may be sufficient for detecting DU contamination on vehicles, it is probably insufficient for DU screening of wounds.

RÉSUMÉ

Le Projet de Procurement de Services pour la Défense 00002199, a fait la demande à CRDO d'entreprendre une étude pour examiner l'efficacité de l'équipement commercial de détection de rayonnement en ce qui concerne la détection de l'uranium appauvri (DU) sur le champ de bataille. Cette étude servira a guider le développement de doctrine afin que des procédures peuvent être suivies lorsqu'il y a contamination de DU. Inclus dans ce travail sont: quelques études spectroscopiques de munitions de DU, des essais de détection en la présense de DU en utilisant une variété de sources ainsi qu'une étude sur l'effet de l'attenuation des rayonnement bêta par le tissu humain. Également, un voyage a été fait au service Superbox à Aberdeen Proving Ground afin de verifier la possibilité d'évaluer l'équipement des Forces Canadiennes (FC) dans un environnement réel contaminé avec du DU.

Cette étude a établi un certain nombre de faits importants concernant la detection du DU par les FC. On a demontré que l'équipement commercial peut détecter l'émission d'α, β, et γ par des sources d'uranium, par contre la détection β est de loin la méthode préférée à utiliser lorsqu'il y a de la contamination. La sensibilité de la sonde alpha-bêta ABP-100 (en mode β) en ce qui concerne la détection de DU est approximativement 0,5 Bq/cm^2 lorsqu'il y a de la contamination répandue sur une grande surface. Cependant, due au fait que l'atténuation des rayonnements bêta par le tissu est considérable, l'efficacité de ce détecteur en détectant des tessons de DU encastrés dans les blessures devient pauvre. Ainsi, malgré que ces dispositifs peuvent être suffisants pour détecter de la contamination de DU sur les véhicules, ils sont probablement insuffisants pour détecter la présense de DU dans les blessures.

EXECUTIVE SUMMARY

Background: Defence Services Procurement Project 00002199 is procuring a large suite of radiation detection equipment for the CF in operations where there is a risk of radiological exposure. One of the hazards against which the CF must be protected is that of depleted uranium (DU). At the request of the project, DREO has undertaken a study of commercial radiation detection equipment for the detection of DU.

Results: This work has demonstrated that DU sources that may be found on the battlefield have at least the activity of check sources, and so should be treated with caution. While α, β, and γ emissions of this source can be detected by the equipment tested in this study, the most effective method for contamination survey is with the use of beta detection instrumentation. The sensitivities of two beta survey instruments for DU detection are evaluated. The shielding effect of tissue is also evaluated, demonstrating that these instruments will probably be insufficient for screening for small pieces of DU in wounds.

Significance and Future Plans: This work can be used by 00002199 to develop doctrine for the CF to operate in areas where the use of, or contamination by, DU is suspected. However, this work should be augmented by actual field trials in a DU-contaminated environment. DREO has initiated discussions with the Aberdeen Proving Ground Superbox facility, and with two US agencies that may be willing to collaborate in the use of this facility. Work on such co-ordination will continue, and DND would be well advised to pursue this work.

Haslip D. S., Cousins T., Estan D., and Jones T. A., Field Detection of Depleted Uranium: Final Report of Tasking W28476KR00Z (DSSPM) (U), Defence Research Establishment Ottawa, DREO TM-2000-049, April 2000.

SOMMAIRE

Étude Préliminaire: Le Projet de Procurement de Services pour la Défense 00002199 obtiendra une grande variété d'équipement de détection de rayonnement pour les FC qui joueront un rôle où il y a un risque d'exposition radiologique. Un des risques contre lesquels les FC doivent être protégées est celui de l'uranium épuisé (DU). Suite à la demande du projet, CRDO a entrepris une étude de matériel commercial de détection de rayonnement pour la detection de DU.

Résultats: Ce travail a démontré que les sources de DU qui peuvent être trouvées sur le champ de bataille ont au moins des niveaux d'activité égales aux sources de contrôle, et ainsi devrait être traité avec prudence. Malgré le fait que les émissions α, β, et γ de DU peuvent être détectées par l'équipement évalué dans cette étude, la méthode la plus efficace pour l'enquête de contamination est sans aucun doute, celle qui engendre la detection d'émissions bêta. La réaction au DU de deux instruments sensibles aux émissions bêta sera évaluée. L'effet d'atténuation du tissu humain est également évalué, démontrant que ces instruments seront probablement insuffisants à identifier de petits morceaux de DU dans les blessures.

Importance et Futurs Plans: Ce travail peut être employé par le projet 00002199 pour développer une doctrine pour les FC, afin qu'elles puissent fonctionner dans des zones où on croie y avoir de l'utilisation, ou de la contamination de DU. Cependant, on devrait ajouter à ce travail, des évaluations dans un environnement réel contaminé avec du DU. CRDO a initié des discussions avec le personnel au service Superbox à Aberdeen Proving Ground à ce sujet. Également, deux agences américaines ont éprouvé de l'intérêt dans une collaboration afin d'utiliser ce service. Des discusssions concernant cette collaboration continueront, et MDN serait bien avisé de poursuivre ce travail.

Haslip D. S., Cousins T., Estan D., and Jones T. A., Détection dans le champs de bataille d'uranium appauvri, Centre de recherche pour la défense Ottawa, DREO TM-2000-049, May 2000.

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1 INTRODUCTION

1.1 Properties of Uranium

Uranium is a naturally occurring grey metal. It was discovered in 1789, and first isolated in 1841. Its radioactivity was discovered in 1896 by Henri Becquerel [1]. It is very dense (19 g/cm^3) with a relatively high melting point (1132 °C). In nature, it exists as three isotopes: ^{234}U (0.0055%), ^{235}U (0.7200%), and ^{238}U (99.2745%).

Uranium's chief uses today are in nuclear weapons and as a fuel in nuclear reactors. Both applications exploit the propensity of ^{235}U to fission when bombarded with neutrons. In fact, natural uranium must be "enriched" in ^{235}U to be used in a nuclear weapon or as a nuclear fuel (heavy-water-cooled reactors can and do use non-enriched uranium). The enrichment process increases the ^{235}U content to 3-5% for commercial reactors, and up to more than 20% for research reactors, naval propulsion reactors, and nuclear weapons [2]. This process also increases the ^{234}U content and leaves behind "depleted uranium" (DU). Depleted uranium is, as the name suggests, depleted in the lower-mass components of natural uranium, having a composition more like 0.001% ^{234}U, 0.199% ^{235}U, and 99.800% ^{238}U [3]. This will vary, depending on the enrichment process. The depleted product has no application in the nuclear industry. However, DU's high density makes it highly desirable for use as a penetrator in military projectiles, or as armour to protect against such projectiles. Indeed, DU is used by many armed forces worldwide in such applications (although Canada no longer uses DU in its armaments). Commercial uranium-based chemicals are also likely to be DU, since it is less expensive than natural uranium.

There are drawbacks to this usage. First, DU is pyrophoric [3]; this means that in a high-velocity impact of penetrator on armour, it has a tendency to ignite spontaneously, sending tiny particles consisting mostly of uranium oxides into the air, from which they can be inhaled. Second, DU is both radioactive (although it is classified as a low-activity material) and chemically toxic. These two facts together mean that there is the potential for soldiers to inhale DU on the battlefield, with possible short- or long-term consequences. Quantification of these consequences is a topic of ongoing debate.

Prevention of health consequences through prophylaxis or hazard avoidance is an obvious goal. Accomplishing this goal requires detection of the potential hazard. Since DU is radioactive, it can be detected with radiation detection equipment such as that procured by DND for Operations Kinetic and Palladium and to be procured for Project 00002199 [4]. However, the efficacy of these devices for detection of reasonable quantities of DU under realistic conditions has not been studied. That is the subject of this report.

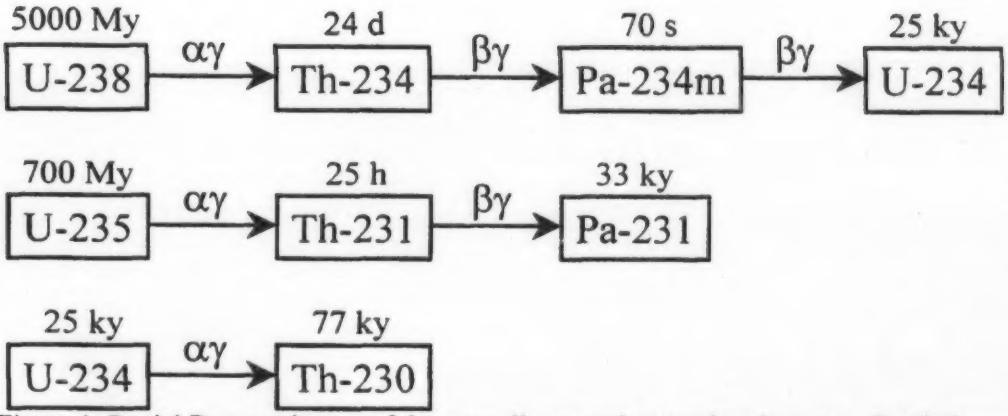

Figure 1: Partial Decay schemes of the naturally occurring uranium isotopes. Symbols above the arrows indicate the nature of the radioactive decay. Times above the boxes indicate half-lives for decay.

1.2 Radioactive Decays

As noted above, there are three naturally occurring isotopes of uranium. Their partial decay pathways are shown in Figure 1. It shows, for instance, that ^{235}U decays via alpha and gamma emission to ^{231}Th, which then decays via beta and gamma emission to ^{231}Pa. In all cases, the decay chains are stopped at the first long-lived (thousands of years) isotope. The significance of this is that, for a sample of processed uranium (such as would be found on the battlefield), only the decays shown would contribute to the detectable activity. Further build-up of other daughter nuclei only occurs in very old (tens or hundreds of thousands of years) uranium samples, such as in uranium ore. This is shown graphically for the ^{238}U decay chain in Figure 2; the short-lived daughters come into equilibrium with the parent after about four half-lives. For ^{235}U, this means that ^{231}Th comes into equilibrium with the parent within about four days.

The object of looking at the decay chains is to differentiate between the emissions of the three isotopes. This is facilitated by considering the three decay chains simultaneously, since the decays depicted above or below one another in the figure have very similar properties. The first decay in all cases is an $\alpha\gamma$ decay to a thorium isotope. The alphas are all about the same energy (although they decrease somewhat in energy for the higher-mass isotopes), and the gammas are all low-energy (below 50 keV). At this point the ^{234}U decay chain effectively stops. For the other two, the decay continues with a $\beta\gamma$ decay to protactinium. The betas and gammas are all of moderate to low energy (beta endpoints below 300 keV, gammas below 200 keV). At this point, the ^{235}U decay stops, and the ^{238}U decay continues with a second $\beta\gamma$ decay. This decay proceeds almost

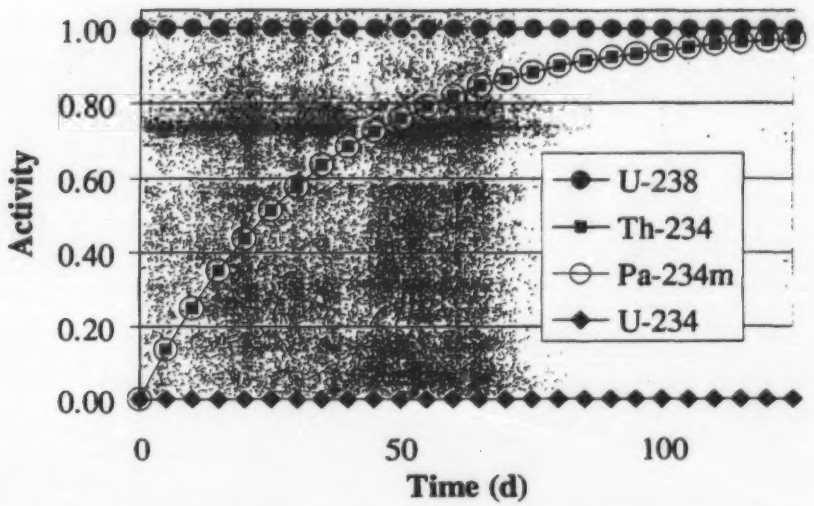

Figure 2: Activities of ^{238}U, its two short-lived daughter products, and the long-lived daughter that follows them, as a function of time. Note how the activities of the short-lived daughters are essentially equal to that of the parent after 100 days (approximately 4 half-lives), but that the activity of the long-lived daughter remains very small over the same period.

exclusively by the emission of a very energetic β (2.3 MeV); the gamma decay also includes a low-probability branch to some energetic gamma rays (766 keV and 1001 keV). This makes a ^{238}U source much easier to detect and identify (both by beta and gamma emission) than either of the other two isotopes. ^{234}U, on the other hand, has no associated β decays, with only low-energy gammas. Because of the aforementioned trend in alpha energies, however, ^{234}U presents a greater inhalation hazard [5].

2 STATEMENT OF WORK

The statement of work for this engineering study contains the following components:

1. Examination of a DU penetrator – to evaluate activity levels.
2. Evaluation of field equipment with a large DU source – to assess capability for DU detection.
3. Evaluation of a subset of the equipment with smaller sources – to assess capability for DU detection with realistic quantities of DU.
4. Evaluation of field detectors with small DU sources and tissue-equivalent plastic – to assess capacity for detecting DU shrapnel in wounds.
5. Assessment of Aberdeen Proving Ground "Superbox" [6] facility – to determine feasibility of performing trials with an ultra-realistic DU penetrator.

Each of these is addressed in turn in the next section.

3 TESTS AND RESULTS

3.1 Activity of a DU Round (SOW #1)

3.1.1 Methodology

The activity of an unknown source can be calculated by comparing its gamma-ray spectrum to that of a standard source of a known activity. The basic formula for this calculation is as follows:

$$A_{unknown} = A_{standard} \times \left(\frac{N_{unknown}}{N_{standard}}\right) \qquad (1)$$

where $A_{unknown}$ is the activity to be determined, $A_{standard}$ is the activity of a standard source, and $N_{unknown}$ and $N_{standard}$ are the numbers of counts in the peaks in the gamma-ray spectra of the unknown and standard samples. It is assumed, of course, that the counting geometries for the two measurements are identical.

The values of N are determined by integrating a common 'peak' area for both energy spectra. In this experiment, peak area measurements were determined using two separate radiation detection systems. The first was the MicroSpec II 2"x2" NaI gamma probe [7], the second was the EG&G Ortec high efficiency Germanium system [8] The standard was a natural-uranium liquid calibration source with a total uranium activity* of 598 nCi (22.126 kBq).

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* The "activity" of a source can be defined as (a) the decay rate of a given nucleus or nuclei, or (b) the decay rate of a given nucleus or nuclei, plus the decay rate of all daughter nuclei. While the health hazard depends on the decay rate of all nuclei, it does so in a nucleus-dependent fashion; thus, it is more convenient to express the activity in terms of definition (a) and use knowledge or estimates of the source age to calculate the activities of any daughters. Definition (a) will be used throughout this report.

Figure 3: MicroSpec II NaI Spectrometer System

According to measurements made by the manufacturer, the activity of ^{238}U in this source is 291 nCi. Since the manufacturer assessment was almost five years prior to this work, we may safely assume that the short-lived daughters (particularly ^{234m}Pa) have come into equilibrium with the ^{238}U, and have the same activity.

3.1.2 MicroSpec II Measurements

All MicroSpec II (Figure 3) measurements were made in the DREO Low Level Counting Facility (Figure 4). This lead cave reduces ambient background by a factor of approximately 10, ie: normal DREO background is about 0.1 μSv/h, but cave background is about 0.006 μSv/h.

In order to compare the DU bullet and the calibration source, both sources and a background spectrum were measured (separately) for 12 hours, with the sources approximately 10 cm from the effective centre of the NaI crystal. These energy spectra were then loaded into a spreadsheet for analysis. There are two distinct energy peaks that were used in this calculation. These are the 766 keV and 1001 keV peaks from the decay of ^{234m}Pa discussed above (see Figure 5). Using Equation (1) above we can calculate the activity of ^{238}U in the DU round ($A_{unknown}$) as seen below:

$$A_{unknown}(750) = (291\,\text{nCi}) \times \left(\frac{290000}{3550}\right)$$

$$= 23700\,\text{nCi}$$

$$= 23.7\,\mu\text{Ci}$$

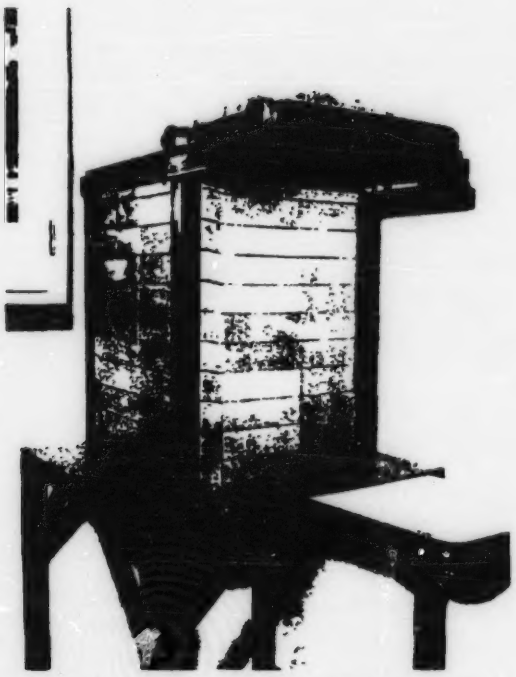

Figure 4: Low Level Counting Facility

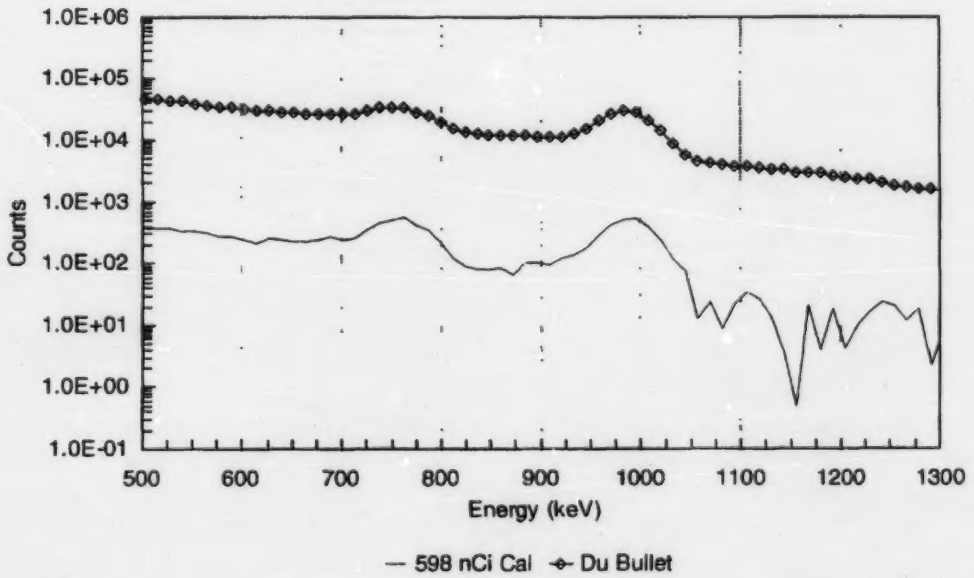

Figure 5: MicroSpec II Energy Spectra

$$A_{unknown}(1000) = (291\,nCi) \times (\frac{217000}{3140})$$
$$= 20152\,nCi$$
$$= 20.2\,\mu Ci$$

This calculation, however, is prone to error due to the large width of the Region Of Interest (ROI) surrounding the peaks. In this instance, for the 766 keV peak, we spanned the area from 700 - 824 keV for the above calculation. If we instead tightened our ROI from 740 - 775 keV we now calculate an activity of 20.0 μCi. This is a relative change of 15.6%. Again, if we use the same approach for the 1001 keV peak and change from the original ROI of 900 - 1045 keV to 975 - 1025 keV, we now calculate an activity of 35.8 μCi, a relative change of 17.4%. Thus, this calculation is at least 15% uncertain.

3.1.3 Germanium System Measurements

The EG&G Ortec Germanium system (Figure 6) provides a much higher resolution energy spectrum than the MicroSpec II (see Figure 7). This in turn provides a more precise determination of peak activity (as a result of a smaller ROI). As can be seen in Figure 7 the definition of the energy peaks is far superior to that seen in the spectrum produced by the MicroSpec II NaI probe. Therefore, there are far fewer extraneous counts that may skew the calculation of activity.

The Ge test system also uses a lead cave to reduce ambient background, however, it is still necessary to take background measurements and subtract this energy spectrum from any low count rate sources, such as the calibration source used here.

Again, we are interested in the peak areas for the two energy points of 766 and 1001 keV.

$$A_{unknown}(750) = (291\,nCi) \times (\frac{20100}{360})$$
$$= 16200\,nCi$$
$$= 16.2\,\mu Ci$$
$$A_{unknown}(1000) = (291\,nCi) \times (\frac{92300}{1910})$$
$$= 14100\,nCi$$
$$= 14.1\,\mu Ci$$

These results are considerably lower than those obtained in the previous section. However, given the quality of the gamma-ray spectra, it is likely that these latter results are more accurate. Thus, taking the average of the above two calculations, the ^{238}U activity of the DU round is approximately 15.2 ± 1.5 μCi.

Determining the total activity of the round requires knowledge of the isotopic composition of the object. Unfortunately, it is not possible to elucidate from these spectra the exact isotopic composition of the DU round. However, DU normally consists of 80-85% ^{238}U by activity [3]. Thus, the total uranium activity of the round is

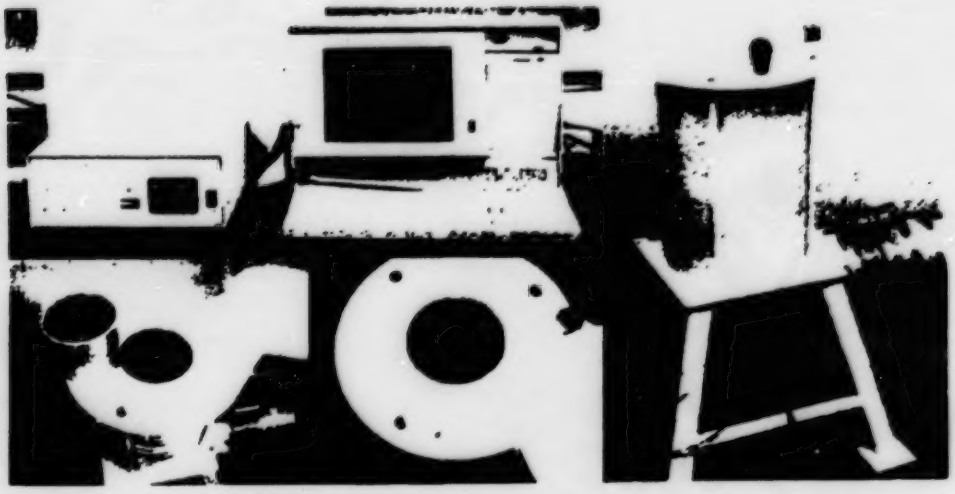

Figure 6: EG&G ORTEC Ge System

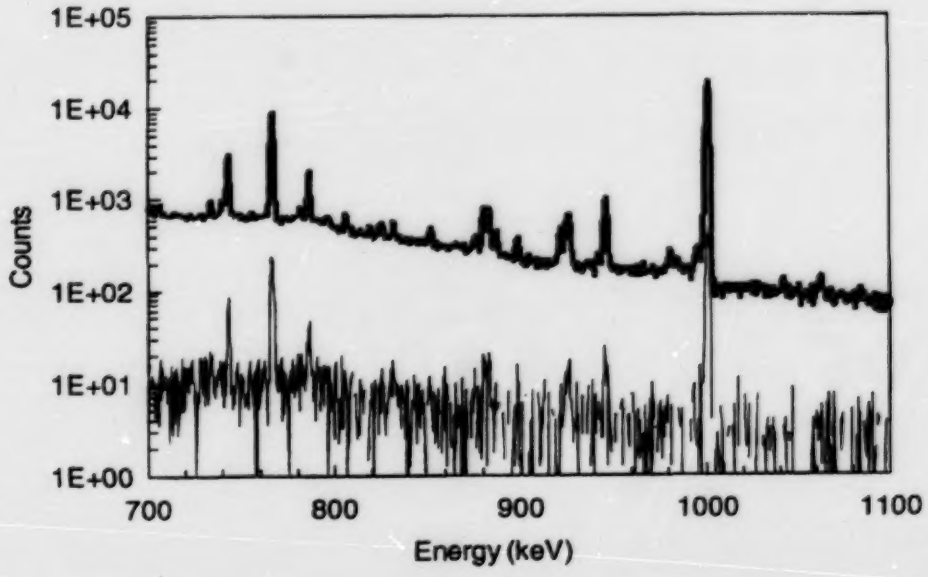

Figure 7: Germanium Spectrum

approximately 18 μCi. This is not an insignificant source, larger than many radiation meter check sources.

3.2 Response of DREO detectors to DU (SOW #2 and SOW #3)

The next objective of the study was to determine how various detectors (which might typically be used by the Canadian Forces) fared in detecting DU. The scope of the study includes establishing if beta or gamma detection was appropriate, whether dosimeters could be utilised for DU detection and the specific response of detectors referenced to the Microspec spectroscopy system. The DU sources used were an approximately 200 kg DU sphere of known activity (32 mCi) and the 20 mm DU penetrator studied above (18 μCi). The gamma detectors used were the MGP DMC 2000S and Siemens EPD Mk2 dosimeters, the NRC UDR-13A, ADM-300C and VDR-2A survey meters. The reference meter was a Microspec gamma spectroscopy system. The beta detectors used were the NRC ABP-100 alpha-beta probe and the VDR-2A with the beta window open. The reference here was the Microspec beta spectroscopy system (HEB). Table 1 through Table 4, below, show the various detectors' dose rate response to the DU sphere and round at various distances, for gamma and beta detection. Table 1 is summarised graphically in Figure 8.

Table 1: Table depicting the response of various gamma detectors to the DU sphere. All dose rates are in μSv/h.

Distance (cm)	Microspec	MGP	Siemens	ADM-300C	UDR-13	VDR-2A
4	27.2	28.8	25.1	32.4	24.5	31.3
10	12.4	16.9	12.3	15.4	13.4	14.0
25	4.28	5.51	4.48	5.34	4.97	4.87
50	1.49	1.90	1.60	1.90	1.87	

Table 2: Table depicting the response of various beta detectors to the DU sphere.

Distance (cm)	Microspec	ABP-100(β)	ABP-100(α)	VDR-2A(β+γ)
4	211 μSv/h	8460 cps	11.2 cps	112 μGy/h
10	180 μSv/h	4820 cps	3.94 cps	66.9 μGy/h
25	41 μSv/h	1930 cps	1.43 cps	24.8 μGy/h
50	14 μSv/h	628 cps	0.447 cps	

Table 3: Table depicting the response of various gamma detectors to the DU round. All data represented below the detector labels are in μSv/h.

Distance (cm)	Microspec	MGP	Siemens	ADM-300C	UDR-13	VDR-2A
4	2.30	9.14	3.54	3.41	1.36	3.31
10	0.379	1.85	0.750	1.31	0.422	0.596

Table 4: Table depicting the response of various beta detectors to the DU round.

Distance (cm)	Microspec	ABP-100(β)	ABP-100(α)	VDR-2A(β+γ)
4	68 μSv/h	1680 cps	2.46 cps	39.5 μGy/h
10	19 μSv/h	556 cps	0.434 cps	14.2 μGy/h

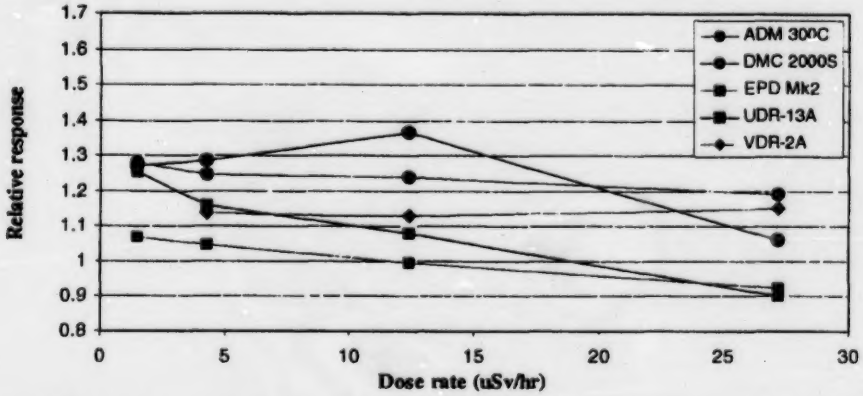

Figure 8: Ratio of measured gamma dose rate to actual dose rate (as measured by the Microspec gamma spectroscopy system) as a function of actual dose rate for five different detectors at various distances from the 32 mCi DU sphere.

Measured dose rates are, for the most part, within 30% of reference values. Differences between these results and previous results [9-11] for ^{137}Cs or ^{60}Co sources are likely due to differences in the gamma-ray spectra of the sources. The gamma-ray spectra of the DU sources are shown in Figure 9; the spectra contain a large number of unresolved low-intensity lines in addition to the two prominent lines studied in the previous section. Note that self-shielding is evident in the spectrum of the DU sphere from the degradation of the low-energy lines.

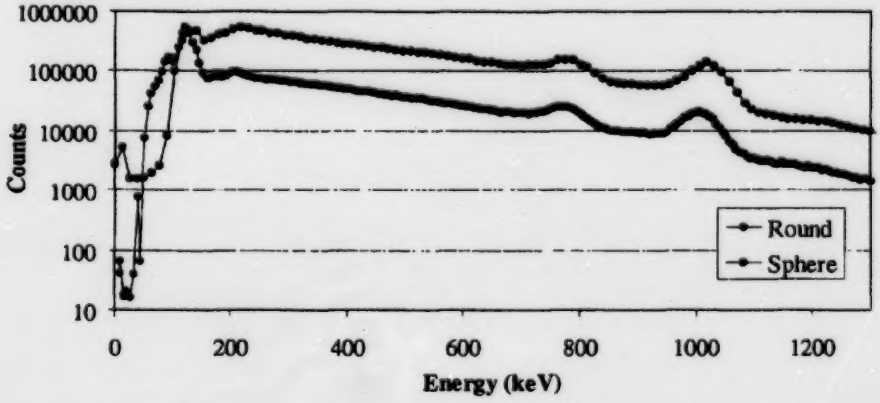

Figure 9: Plot of the gamma spectrum of the DU sphere and the DU round at 4 cm from their respective surfaces for an exposure time of 1 hour

These results indicate that any of the gamma meters, even the dosimeters can be used to detect and locate large quantities of DU, since dose rates are tens of microsieverts per hour at close range. However, the likelihood of encountering a 200 kg piece of DU in a real world scenario is extremely small, to say the least. A more realistic scenario would be the presence of DU dust, shards of DU from a round, or an intact round, as was studied here. Since these dose rates are much smaller, personal dosimeters cannot be used to identify the presence of such an object. In fact, all gamma detection methods are inappropriate. The ADM-300C, being the most sensitive of the three meters, fared most favourably in dose rate mode while scanning near the DU round. However, to see clearly any deflection on the meter, it must be held in close proximity to the round for several seconds. Thus, in a real scenario, where the exact location of the source is not known, the use of the ADM-300C in gamma mode would be inappropriate.

The most effective method of detecting the presence of the DU round is without question through the use of beta detection (the beta spectrum is shown in Figure 10). At 10 cm from the round, both the ABP-100 and the VDR-2A in beta mode yielded unquestionable results, with count rates at least 130 and 70 times above background (background rates for ABP-100 (β) and VDR-2A are 4.31 cps and 0.2 μGy/h, respectively). At this distance, the ABP-100 (α) meter showed only 10 times background. At 4 cm, where absorption of alphas is less of a problem, beta detection is still preferred. The ABP-100 (β) meter gave 400 times background and the VDR-2A gave 200 times background; the ABP-100 (α) gave only 55 times background.

Of course, while a beta count-rate meter is preferred for establishing the *potential* presence of depleted uranium, such a measurement must be verified by spectroscopic means. Since the beta spectrum is somewhat nondescript, the best way to verify the presence of depleted uranium is through a gamma-ray spectrum. This makes spectroscopy an absolute requirement for the field.

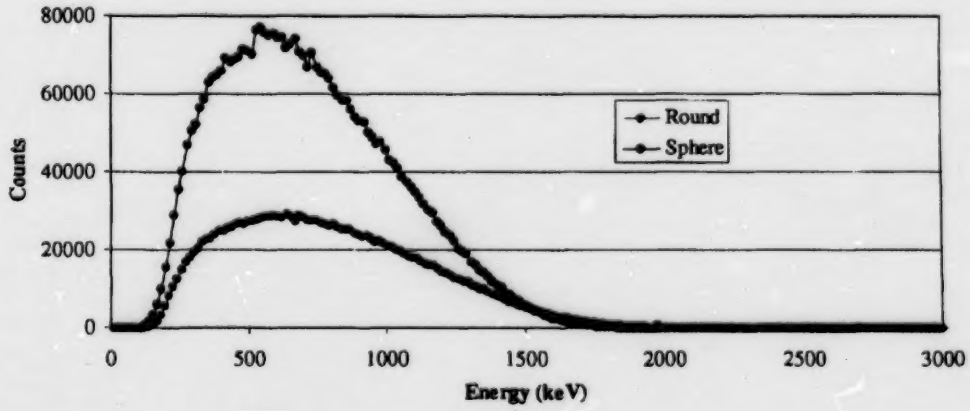

Figure 10: Plot of the beta spectrum of the DU sphere and the DU round at 4 cm from their respective surfaces for an exposure time of 1 hour

3.3 Detection of DU dust (SOW #3)

As mentioned above, the scope of this study is not limited to large or shrapnel-sized pieces of DU. The detection of much smaller amounts of DU, such as scattered dust, is also of concern. In order to ascertain the detectors' efficiency for detecting DU dust, two circular area sources (45 mm diameter) were used. The sources were a 203 Bq "enriched" source and a 102 Bq "depleted" source. The exact compositions of these sources are in Table 5, since neither source is isotopically pure.

The responses of the ABP-100 and VDR-2A to the two area sources are in Table 6. Clearly, the detectors are far more sensitive to the "depleted" source than to the "enriched" one. This is explained simply by recalling the decay properties described in Section 1.2. The "depleted" source is almost pure ^{238}U, and since this isotope is a strong beta emitter, it dominates the beta signal of the source. The derived calibration factors in the table for the "depleted" source are, therefore, essentially calibration factors for ^{238}U alone, although they will be accurate for DU as well, within about 20% (the DU calibration factor should be larger). The signal for the "enriched" source is down by an order of magnitude, which is approximately consistent with the reduction in activity of ^{238}U in this source. This indicates that the signal from both ^{234}U and ^{235}U are quite small relative to ^{238}U.

At this stage, it is also worth noting a lower limit for DU contamination detection with these meters. At the level studied here (approximately 6 Bq/cm^2 for the "depleted" source), the signal-to-background ratio for the VDR-2A is 1.9:1 (background rates are around 0.2 μGy/h with the beta window open). For survey purposes, this is approximately the lower level with which contamination could be detected. Granted, one can detect lower levels of contamination under controlled conditions with long counting

Table 5: Table depicting the proportions of isotopes by activity for both 45 mm area sources used in the study.

"Depleted" (102.4 Bq)		"Enriched" (203.2 Bq)	
Isotope	Proportion (%)	Isotope	Proportion (%)
U-238	97.06	U-238	6.44
U-235	0.11	U-235	4.64
U-234	2.83	U-234	88.39

Table 6: Table depicting the response of the ADM-300 beta probe and the VDR-2A beta+gamma probe to the "depleted" and "enriched" area sources at 4cm from the surface of the detector. All data is background-subtracted.

"Depleted" (102.4 Bq)		"Enriched" (203.2 Bq)	
ABP-100 (β)	VDR-2A (β+γ)	ABP-100 (β)	VDR-2A (β+γ)
20.2 cps	.381 μGy/h	3.20 cps	.0621 μGy/h
6.27 cps/(Bq/cm^2)	0.118 (μGy/h)/(Bq/cm^2)	0.501 cps/Bq/cm^2	0.0097 (μGy/h)/(Bq/cm^2)

times, but this is not to be expected operationally. Thus, the VDR-2A detection limit is approximately 5 Bq/cm^2. The background rate for the ABP-100 in β mode is 4.3 cps, so the rate for the "depleted" source is about 4.7 times background. Thus, one could detect a 2.7 Bq/cm^2 source of this physical size with a 2:1 signal-to-background ratio. Furthermore, since the detector itself is about six times larger than the source in question, one could detect large-area contamination to a limit of probably 0.5 Bq/cm^2.

3.4 Detection of DU in wounds (SOW #4)

This phase of the work examines the efficacy of equipment for detecting DU in wounds. That is, if a shard of DU were embedded in a wound, could it be detected from the surface of the skin with a conventional detector? To examine this question, measurements were made with the ABP-100 (β), VDR-2A, and Microspec II (β probe) at four distances from the 20 mm DU rounds studied previously. For each meter and position, two measurements were made: (a) nothing but air between the source and the detector, and (b) tissue-equivalent plastic in the intervening space. Table 7 through Table 9, below, summarise these results.

It should first be noted that the shielding factors (the decrease of dose rate caused by the presence of the tissue) are nearly constant over this small range of distances, and average about 60. This attenuation affects greatly the meters' sensitivity to DU. Recalling that the background rate for the ABP-100 is 4-5 cps, and that the lower limit for sensitivity corresponds to about twice this value, the ABP-100 could detect a 0 6 cm^3 piece of

Table 7: Table depicting the ABP-100's beta response to the DU round through air and tissue-equivalent plastic. The response is background-subtracted.

Dist (air or tissue)	ABP-100 (β, air)	ABP-100 (β, tissue)	Shielding factor
1.25 cm	2590 cps	54.9 cps	47.2
2.50 cm	1970 cps	37.1 cps	53.1
3.75 cm	1640 cps	23.1 cps	71 0
5.00 cm	1310 cps	19 cps	68.9

Table 8: Table depicting the VDR-2A's beta + gamma response to the DU round through air and tissue equivalent plastic. The response is background-subtracted.

Dist (air or tissue)	VDR-2A (air)	VDR-2A (tissue)	Shielding factor
1.25 cm	121 μGy/h	2.16 μGy/h	56.1
2.50 cm	63.2 μGy/h	1.13 μGy/h	55.8
3.75 cm	39.3 μGy/h	0.63 μGy/h	62.4
5.00 cm	26.5 μGy/h	0.475 μGy/h	55.8

Table 9: Table depicting the Microspec's beta response to the DU round through air and tissue equivalent plastic. The response is background-subtracted.

Dist (air or tissue)	Microspec (air)	Microspec (tissue)	Shielding factor
1.25 cm	372 µSv/h	3.73 µSv/h	99 8
2.50 cm	191 µSv/h	3.02 µSv/h	63.3
3.75 cm	118 µSv/h	1.91 µSv/h	61.8
5.00 cm	77.9 µSv/h	1.08 µSv/h	72.5

shallowly-embedded (1.25 cm) DU, or a 2 cm^3 piece of deeply-embedded DU. The sensitivity of the VDR-2A is approximately half as good. While these values are not enormous, a greater sensitivity would be desirable; the best-case (0.6 cm^3) is still equivalent to a cube 0.8 cm on a side.

3.5 Assessment of APG Superbox (SOW #5)

DREO staff paid a visit to the Superbox facility of Aberdeen Proving Ground in January 2000. This is an impressive facility, permitting live-fire tests of DU and other munitions on anything from steel plates to armoured vehicles. Experiments at this facility could be valuable to 00002199, since they could demonstrate what the nature and extent of DU contamination around a struck vehicle, as well as the size and shape of DU shards from such an incident. As a result of this visit, contacts have been made with US offices with similar interests (US Army Heavy Metals Office, and the Office for the Special Assistant for Gulf War Illness). A joint experiment between TTCP CBD AG44 (The Technical Co-operation Program, Chem-Bio Defence Group, Action Group 44) and one of these agencies seems likely. Attached at Annex A is the preliminary proposal for TTCP research, which must be approved at June's meeting of the CBD Group

4 CONCLUSIONS AND RECOMMENDATIONS

This work has revealed a number of valuable facts affecting the Canadian Forces and their use of radiation detection equipment for detecting DU. These are given below, in the same order as they were presented.

1. The DU round supplied to DREO by the CF has a total uranium activity of 18 μCi, as determined by gamma spectroscopy measurements made with DREO's high-resolution germanium detector. This is a significant quantity of radioactive material, larger than many check sources. It underscores the care with which this material should be treated on the battlefield. It should be noted that although DND has phased out all DU munitions, the potential for exposure remains from DU used by friendly or opposing forces.

2. All of the dosimeters and survey meters tested in this work detected DU, as expected. However, in terms of using this equipment for finding shards of DU, for instance, gamma radiation detectors are, in general, insufficient. Since the dose rate at 4 cm from the DU round is as small as 2 μSv/h, finding an object of this activity with a dosimeter is next to impossible, and detecting it with a gamma survey meter would likely also be a challenge. However, DU can be detected through its beta and alpha emission. In fact, detection of beta radiation is the most effective method for detecting DU. The ADM-300 with the ABP-100 probe and the VDR-2A with the beta window open are both reasonable meters for this task. Of course, any such detection must be verified with gamma spectroscopy.

3. As noted above, DU can be detected through its beta emission. Tests with area sources showed that this emission is dominated by that of ^{234m}Pa in the ^{238}U decay chain (as long as the two are in equilibrium, which will be the case in all uranium processed more than three to four months previously). The beta signals from the other isotopes of uranium are negligible in comparison. The VDR-2A detection limit for DU contamination is approximately 5 Bq/cm^2; for wide area contamination, the ABP-100 detection limit is about 0.5 Bq/cm^2.

4. The presence of 1-5 cm of tissue attenuates the beta count or dose rate by approximately a factor of 60. This means that the ABP-100 is only capable of detecting a 0.6 cm^3 piece of shallowly-embedded DU (1.25 cm), and a 2 cm^3 piece of deeply-embedded DU (5 cm). The minimum detectable size for a DU shard with the VDR-2A is approximately twice as large. These are relatively large pieces of DU; thus, while these meters have some application in this area, they are not capable of detecting arbitrarily-small embedded shards.

5. The Aberdeen Proving Ground Superbox is an excellent facility, capable of doing a wide range of DU-related experiments. DREO is currently in contact with US agencies and is attempting to encourage Superbox experiments under the auspices of TTCP CBD AG44. Decisions on the future of this project will be made this summer.

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ANNEX A: PROPOSAL FOR TTCP CBD AG44 RESEARCH INTO BATTLEFIELD DEPLETED URANIUM

Background: The use of DU (munitions and armour) on the modern battlefield is an accepted fact of life. DU usage can only be expected to increase in the future, as more nations acquire the technology. This usage represents a potential health concern to all countries – not just those who have DU stock – owing to the prevalence of DU shrapnel, fragments and dust in combined (NATO or UN) operations.

Over the past few years, there have been an increasing number of health-related claims (and associated media coverage) from former members of armed forces, specifically claiming DU as a contributing factor in their illness. These claims are especially abundant in CA, UK, and US. As is usual in such cases, the onus is on the various militaries to categorically prove the absence of cause-and-effect.

Technical Problems: The issue of DU exposure and subsequent biological effects is not a trivial one to solve. The issue may be addressed along three lines.

1) Field DU detection: This will allow recording of the precise DU levels to which troops have been exposed.
2) Evaluation of medical effects of DU: Working in concert with 1), this will enable accurate in-theatre prediction of medical effects based on field measurements.
3) Post-mission analysis of personnel: Techniques to accurately quantify DU body burden must be benchmarked.

Technical Solutions: The proposed solutions require participation of many agencies, both within and outside of TTCP.

1) Field DU detection: Efficacy of existing or proposed radiation detection systems for the detection of DU will be evaluated in well-known and controlled fields (under the auspices of AG44).
2) Evaluation of Medical Effects: This is an on-going project of NATO P8 TG006. Agreement has been reached to collaborate and exchange data with AG44.
3) Post-mission analysis of personnel: This will largely be done in various national laboratories. Exchange of information at AG44 will be encouraged.

Field Detection of DU Trials: A well-calibrated, controlled source of post-explosion DU dust has been identified – the US Army Aberdeen Proving Ground (APG) 'Superbox'. This facility consists of a state-of-the-art containment fixture capable of withstanding detonations of 100 lb TNT blast equivalency. Test targets may vary from armour plates to fully loaded combat vehicles. The facility is capable of recording many test parameters (such as gas analysis, ballistic shock instrumentation, high-speed imagery, etc). The option of outside testing is also available at APG.

A recent visit to Superbox by AG44 personnel (Chair and CA) revealed that there are several upcoming tests that are in the planning stage, on which AG44 may be able to "piggyback". These are being done under various auspices (such the Office of the Special Assistant for Gulf War Illness). US has promised additional information on this and other activities. Contacts will be made. An AG44 test in 2001 looks quite feasible.

"Strawman"

1) Decide on appropriate trial parameters. i.e Should the goal of the trial be to hit a vehicle with a DU round, and then determine how well contamination may be monitored ?
   If so the following need to be determined
   - type of vehicle
   - size of round
   - relevant parameters to be measured (air particulate size, reference measurements, etc)
2) Each nation should then decide upon which equipment would be brought to APG for the trials.
3) Test protocols to be established.
4) Finalize plans with APG and other relevant agencies.

Benefits of Approach: The international sharing of data clearly makes this approach useful. In addition, the information will be passed on to TG006, and this will be of help to the medical community. The information will be unclassified, and will assist greatly in future equipment development/procurement. The information will also be of great use to various national groups studying the subject.

Timeframe:

1) Feedback on this document by Jan 31 (under silence procedure)
2) Submit revised document to CBD NRs on Feb 1.
3) Present and solicit approval for work at CBD meeting in June.
4) Flesh out "Strawman" at next AG44 meeting at APG.
5) Conduct trials in 2001.

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At the request of Defence Services Procurement Project 00002199, DREO has undertaken a study to examine the capabilities of commercial radiation detection equipment for the detection of depleted uranium (DU) on the battlefield This work is intended to guide doctrine development for procedures to be followed where DU use or contamination is suspected. This work involved some spectroscopic studies of DU munitions, and detection trials with a variety of DU sources, from large spheres to low-activity area sources. The effect of shielding by tissue was also studied, and a trip was made to the Superbox facility at Aberdeen Proving Ground to assess the possibility for field trials of Canadian Forces (CF) equipment in an actual DU-contaminated environment.

This study established a number of important facts regarding DU detection by the CF. It was shown that while commercial equipment can detect alpha, beta, and gamma emission by uranium sources, beta detection is by far the preferred method to be used for contamination surveys. The sensitivity of the ABP-100 alpha-beta probe (in beta mode) for DU is approximately 0.5 Bq/cm2 when the contamination is over a large area. However, because the attenuation of beta radiation by tissue is so great, the efficacy of this detector for detecting shards of DU embedded in wounds is much poorer. Thus, while these devices may be sufficient for detecting DU contamination on vehicles, it is probably insufficient for DU screening of wounds.

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